CHARACTERISATION AND MODELLING OF STATIC RECOVERY PROCESS OF PLAIN CARBON STEEL

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurently submitted for award of other degree.

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For my loving father, mother and family

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ABSTRACT

This thesis is an investigation of static recovery process due to different pre – strain, temperature and time on recovery process. In this project, plain carbon steel specimens were subjected to tensile test and heat treatment process. The specimens were the tensile test specimen shape according ASTM E8. Box furnace was used in this project to perform the heat treatment of the specimens. The specimens were heated to a temperature which is below the recrystallization temperature with certain range of time. In this research, the recovery temperature was varied to 100^{o}C, 200 ^{o}C, 300 ^{o}C and 400 ^{o}C. The pre – strain value was varied to 5%, 10%, 15% and 20% which is the value before the specimen break. The time was varied to 1 hour, 2 hours, 3 hours and 4 hours in order to analyze the static recovery process due to different time. The change of stress values were taken before and after static recovery for all variables to calculate the degree of recovery, X_{rec} by using Friedel's model equation. The graphs were plotted to analyze the relationship between degree of recovery with these variables. The linear equations that obtained from each graph were compared with Friedel's model equation in order to calculate the activation energy, Q. In this research, the activation energy for different temperature (1 hour fixed time, 10% pre - strain) was 118 kJ/mol and the value for different time (300^{o}C fixed temperature, 5% pre - strain) was 162 kJ/mol. Finally, the activation energies that obtained were compared with other journal in order to validate the static recovery process of plain carbon steel by using Friedel's method equation.

ABSTRAK

Tesis ini adalah kajian mengenai proses pemulihan statik untuk pelbagai ketegangan spesimen, suhu dan masa pemulihan. Dalam projek ini, spesimen besi keluli akan diuji dengan analisis ketegangan dan proses rawatan haba. Bentuk spesimen yang digunakan dalam projek ini adalah ASTM E8. Relau akan digunakan untuk proses rawatan haba dalam projek ini. Spesimen akan dipanaskan kepada suhu dan masa tertentu di bawah suhu penghabluran semula. Dalam projek ini suhu dibezakan kepada 100^{o}C, 200 ^{o}C, 300 ^{o}C dan 400 ^{o}C. Nilai pra – tegasan dibezakan kepada 5%, 10%, 15% dan 20% di mana nilai tegasan sebelum spesimen putus. Manakala, untuk perubahan masa, tempoh pemanasan dibezakan kepada 1 jam, 2 jam, 3 jam dan 4 jam. Perubahan nilai tegasan sebelum dan selepas pemulihan statik akan dianalisis untuk semua pembolehubah untuk pengiraan darjah pemulihan, X_{rec} mengunakan persamaan model Friedel. Hubungan di antara darjah pemulihan dan pembolehubah tersebut dianalisis melalui graf. Persamaan linear yang terhasil daripada graf akan dibandingkan dengan persamaan model Friedel untuk pengiraan tenaga pengaktifan, Q. Dalam projek ini, tenaga pengaktifan yang terhasil daripada perbezaan suhu (masa ditetapkan 1 jam, 10% pra - tegasan) ialah 118 kJ/mol, manakala untuk perbezaan masa (suhu ditetapkan 300^{o}C, 5% pra - tegasan) nilainya ialah 162 kj/mol. Akhir sekali, nilai ini dibandingkan dengan jurnal lain untuk sahkan proses pemulihan statik untuk besi keluli dengan menggunakan kaedah persamaan Friedel.

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LIST OF SYMBOLS

ε	Strain
σ	stress
σ_o	Yield stress of the undeformed specimen
σ_m	Maximum yield stress
σ_r	Yield stress of the static recovery
C	Constant
X	Degree of recovery
t	Time
Q	Activation Energy
T	Temperature
R	Gas constant (8.314 J/mol.K)
M	2 for BCC metal
α	Constant
G	Shear modulus
b	Burgers vector
ρ	Dislocation densities
σ_d	Stress due to dislocation

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
AISI	American Iron and Steel Institute
C	Carbon
Cu	Copper
Mn	Manganese
Si	Silicon
P	Phosphorus

CHAPTER 1

INTRODUCTION

1.1 PROJECT OVERVIEW

Static recovery is part of annealing process which is used for metal heat treatment. This process is done to change the properties of the material such as strength and hardness. When metal is heavily in cold- worked, much of strain energy expanded in the plastic deformation is stored in the metal in form of dislocations and other imperfections such as point defects. When cold – worked is reheat in the recovery temperature range just below recrystallization temperature range, sufficient thermal energy is supplied to rearrange the dislocation into lower energy configuration. During recovery, the strength of a cold – worked is reduced slightly but the ductility is significantly increased.

Basically, there are three types of plain carbon steel which are low carbon steel, medium carbon steel and high carbon steel. These types of carbon steel are differentiated with amount of carbon content. Low carbon steel or mild steel is approximately 0.05% – 0.15% carbon content. Example of this low carbon steel is AISI 1080 steel, AISI 1006, AISI 1009 and AISI 1020.

The second type of plain carbon steel is medium carbon steel. It has approximately 0.30% – 0.59% carbon content. The example of this type of steel is AISI 1040 steel, AISI 1023, AISI 1030 and AISI 1046. The third type of plain carbon steel is high carbon steel. In this steel, the carbon content is about 0.60% - 0.99%. The example of this steel is AISI 1055 and AISI 1070.

Plain carbon steel is used in this project. The heat treatment which is annealing is performed to change the mechanical properties of this material. The yield strength with different pre-strain (5%, 10%, 15% and 20%) can be determined using tensile test. In the static recovery process, the grain of material structure will be recovered from cold-worked imperfections. The change of stress value before and after static recovery is related to the amount of grain recovery. The behavior of this material can be characterized by using static recovery model.

1.2 PROBLEM STATEMENTS

The problem in this project is to find the change of stress value after static recovery for samples that has been pre - strain. The stress value before and after static recovery is different because of the grain structure is recovered. To find the stress value, the specimen of AISI 4140 steel is subjected to the tensile test with pre – strain values.

1.3 PROJECT OBJECTIVE

To validate static recovery process using Friedel's model for plain carbon steel.

1.4 PROJECT SCOPES

- Specimens are subjected to tensile test pre – strain.
- Using lathe machine to shape the specimens.
- Using material plain carbon steel.
- Using box furnace to perform heat treatment.
- Varying pre – strain (5%, 10%, 15%, 20%).
- Varying recovery temperature (100^0C, 200^0C, 300^0C and 400^0C)
- Varying recovery time (1 hour, 2 hours, 3 hours and 4 hours)
- Analyze static recovery using Friedel's model.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this literature review is to get information about the project from many sources such as books, journals, technical papers and web sites. In this chapter, information that contained is used to compare and to get the result of the project. The source that contain in this chapter is also used as a guild to conduct the overall project.

2.2 ANNEALING

Annealing is a heat treatment process where metal is heating up to certain temperature in certain range of time [2]. The purpose of annealing process is to change the properties of the material. There are three parts of process occur in annealing as we increase the heat treatment temperature. The three regions are recovery, recrystallization and grain growth. This process that softens the cold – worked metal is called annealing and there are also term partial anneal and full anneal that refer to degree of softening [1]. An annealing operation that involves heating up to the austenite region is called a full anneal. There are also annealing that heating to a point just below the austenite transition temperature which is called partial anneal. It does not soften the steel as effectively as a full anneal. But since there is no crystal structure change, it usually produces less distortion than full anneal [2].

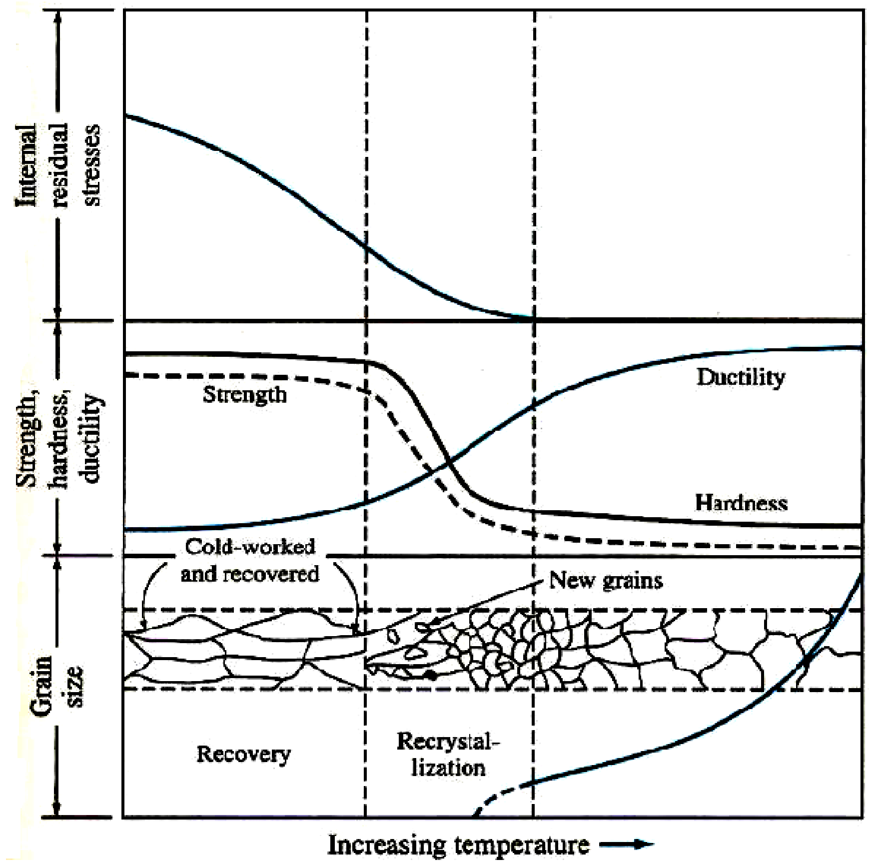

Figure 2.1: Structure and mechanical change during annealing [1]

2.2.1 Recovery

The term recovery comes from the observation that some of the physical properties of the material are recovered [3]. Recovery is the first stage in annealing process which is below the recrystallization temperature range. In recovery temperature range, internal stresses in the metal are relieved. When sufficient thermal energy is supplied, the dislocations of cold – work will rearrange themselves into lower energy configuration with low angle grain boundaries. Since many dislocations are rearrange to lower energy configuration, the internal energy of the recovered metal is lower than the cold – work metal. As the result, the strength of metal is reduced slightly and the ductility is increased significantly [1].

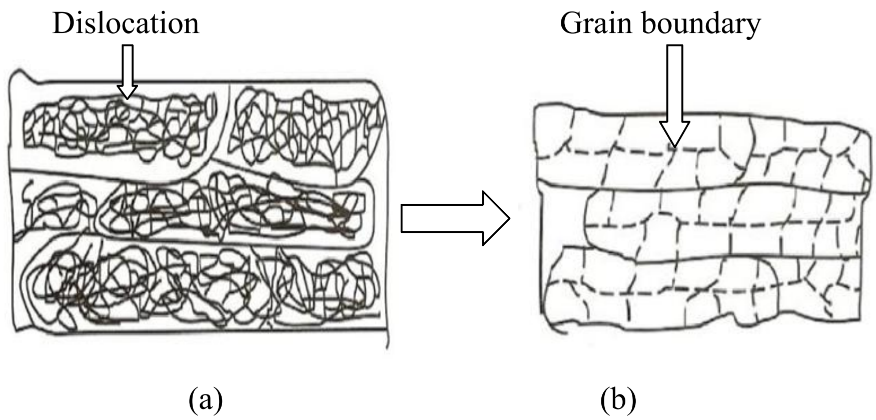

Figure 2.2: (a) Cold- work dislocation. (b) Recovered sub grains [3]

2.2.2 Recrystallization

The process of recrystallization is importance in the metal-forming process because it restores the ductility of metal which becomes hardened by plastic deformation, and controls the grain structure and the mechanical properties of the final product [5].

If we exert hammer force to the one of metal surface, the grains near the surface will become distorted and the hammered surface will plastically deform. If we wish to restore its microstructure to unstrained state, new grains must be formed and some of the metal surface must be plastically deform. As the metal is heated to its annealing temperature, it will become weaker. Then the microstructure such as dislocations and distortion part will adjust themselves to neutral and unstressed condition as explain in recovery process. By the time the temperature reach to certain point, the metal will be recrystallyzed [2]. This is the second stage of annealing process after recovery.

During the recrystallization stage, new grains are nucleated in the recovered metal and begin to grow forming recrystallized structure. After certain range of temperature, the cold – worked structure is completely replaced with recrystallization grain [1].

Recrystallization of a deformed metal is depending not only on the overall stored energy but also on microstructure of the material [5].

The grain size of new recrystallized structure is depend on the amount of cold – worked, temperature of anneal, time range and composition of material [3]. Some of the characteristics are:

I. The smaller the amount of cold – worked, the higher the temperature to cause recrystallization [3].
II. When the temperature for recrystallization is increase, the time necessary to complete it is decrease [1].
III. The greater the degree of deformation, the lower the annealing temperature for recrystallization and smaller the recrystallizaton grain size [1].
IV. The recrystallization temperature decrease with increasing purity of the metal. Solid solution of alloying addition always increases the recrystallization temperature [1].

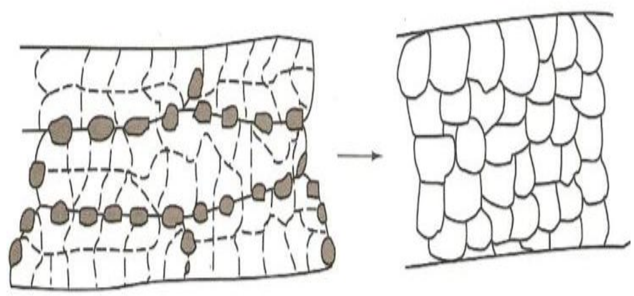

Figure 2.3: Start of recrystallization to the fully recrystallized [3]

2.2.3 Grain Growth

Grain growth starts when the recrystallization is complete. It is characterized by a gradual decrease in strength of the material to increase its grain size. When the growth occurs uniformly among all of the grains which is the average of the grains size are about the same, it is called normal grain growth. When the size some of the grain much larger than others, it called abnormal grain growth or secondary recrystallization [3]. It will result in a new grain structure with a low dislocation density. The loss by these processes of the dislocations produces mechanical softening of the material [6].

2.3 TENSILE TEST

Tensile test is used to evaluate the strength of metal and alloys. In this test, the sample is pulled with axial load until fracture occurs in a relatively short time at a constant rate.

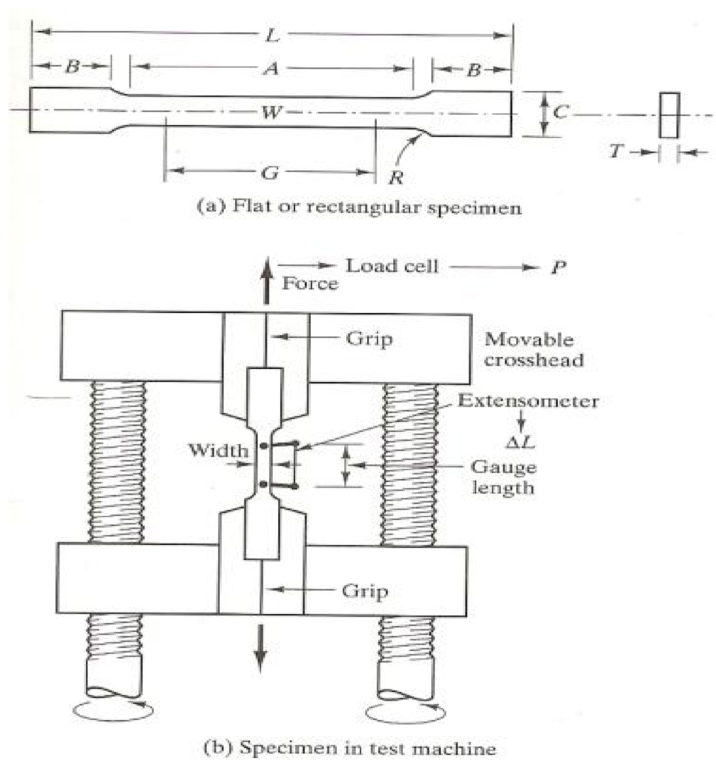

Figure 2.4: Performing tensile test[1]

Figure 2.4 shows that the process of tensile test.This test tend to pull a member apart. The tensile test machine apply a tensile load when one end of the test sample is attached to a movable crosshead with the other end fixed to stationary member. The